

REMARKS

In view of the above amendments and the following remarks, reconsideration and further examination are requested.

The specification and abstract have been reviewed and revised to make a number of editorial revisions. Due to the number of changes involved, a substitute specification and abstract have been prepared and are submitted herewith. No new matter has been added. Enclosed is a marked-up copy of the original specification and abstract labeled **“Version with Markings to Show Changes Made”** indicating the changes incorporated into the substitute specification and abstract.

Claims 1, 3, 4 and 5 have been rejected under 35 U.S.C. §103(a) as being unpatentable over Hofstetter (US 5,437,242). Claims 2 and 6 have been rejected under 35 U.S.C. §103(a) as being unpatentable over Hofstetter in view of Fuerhoff (US 5,882,402). Claims 1-6 have been cancelled and are replaced with new claims 7-14. These rejections are submitted to be inapplicable to the new claims for at least the following reasons.

Claim 7 is patentable over the Hofstetter, relied upon by the Examiner, since claim 7 recites an apparatus having, in part, level position controlling means for controlling a level position of a crucible via a lifting device, wherein the level position controlling means controls the level position of the crucible based on an ascent speed adjusted by an adjustment value when certain criteria are satisfied and the level position controlling means controls the level position of the crucible based on just the ascent speed when the certain criteria are not satisfied. Hofstetter fails to disclose or suggest level position controlling means as recited in claim 7.

Hofstetter discloses an apparatus for controlling a melt level when pulling a single crystal. The apparatus includes an image-processing device 7 that determines an actual distance between a cover 5 and a surface of melt 2 by observing the reflection of the cover 5 on the surface of the melt 2 via a camera 1. The image-processing device 7 outputs an actual signal X to a control device 8 which compares the actual signal X to a predefined set point signal Y, which is proportional to the desired distance, and if a deviation is observed, the control device 8 outputs a control signal Z to adjust the height of a crucible 11, 12. (See column 5, line 25 - column 6, line 35.) Based on the above description, it is apparent that the control device 8 only controls the crucible level based on an actual level position measurement result. Further, the Examiner admits that Hofstetter fails to

disclose that control device 8 relies on a decrease in the volume of melt in controlling the crucible level.

However, the Examiner has indicated that it would be obvious to one of ordinary skill in the art that melt level is directly related to the volume of melt and that it is inherent in Hofstetter that the control device 8 controls the crucible level by calculating a decrease in the volume of melt and that it would have been obvious to one of ordinary skill in the art to maintain the level of melt. The Applicants strongly disagree with the Examiner's rationale. While it may be important to maintain a constant level of melt, the apparatus in Hofstetter strictly relies on observing the reflection of the cover 5 on the surface of the melt 2 to control the crucible level with the control device. Hofstetter fails to disclose or suggest that the control device 8 uses the volume of the melt to control the crucible level. Further, the Examiner's indication that it would be inherent to control the crucible level in this fashion because it is obvious is not accurate, since the control device utilizes the actual level position measurement result determined based on the reflection of the cover 5. Therefore, Hofstetter does not contemplate the control device 8 using the volume of the melt to control the crucible level. As a result, the Examiner's indication that it is inherent that the control device 8 uses the volume of the melt to control the crucible level is improper and contrary to what is actually disclosed in Hofstetter.

Further, it is apparent that the control device 8 does not control the height of the crucible 11, 12 based on an ascent speed adjusted by an adjustment value when certain criteria are satisfied and controls the level position of said crucible based on just the ascent speed when the certain criteria are not satisfied. As a result, Hofstetter fails to disclose or suggest the invention as recited in claim 7.

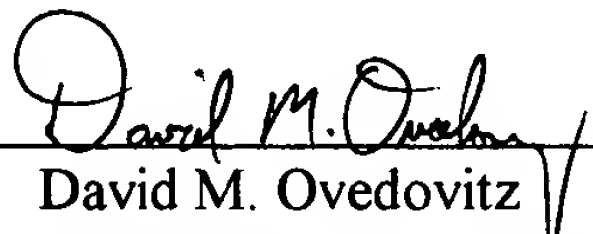
Further, in section 3 of the Office Action, the Examiner contends that Fuerhoff discloses a control unit that adjusts the rotation, pull, and/or heating parameters to maintain a constant diameter of a crystal. However, even if the Examiner contention is accurate, Fuerhoff fails to disclose or suggest level position controlling means for controlling a level position of a crucible via a lifting device, wherein the level position controlling means controls the level position of the crucible based on an ascent speed adjusted by an adjustment value when certain criteria are satisfied and the level position controlling means controls the level position of the crucible based on just the ascent speed when the certain criteria are not satisfied, as recited in claim 7.

Because of the above mentioned distinctions, it is believed clear that claims 7-14 are allowable over the references relied upon by the Examiner. Furthermore, it is submitted that the distinctions are such that a person having ordinary skill in the art at the time of invention would not have been motivated to make any combination of the references of record in such a manner as to result in, or otherwise render obvious, the present invention as recited in claims 7-14. Therefore, it is submitted that claims 7-14 are clearly allowable over the prior art of record.

In view of the above amendments and remarks, it is submitted that the present application is now in condition for allowance. The Examiner is invited to contact the undersigned by telephone if it is felt that there are issues remaining which must be resolved before allowance of the application.

Respectfully submitted,

Keiichi TAKANASHI et al.

By: 
David M. Ovedovitz
Registration No. 45,386
Attorney for Applicants

DMO/jmj
Washington, D.C. 20006-1021
Telephone (202) 721-8200
Facsimile (202) 721-8250
July 30, 2002

RECEIVED

JUL 31 2002

APPARATUS FOR PULLING A SINGLE CRYSTAL TECHNOLOGY CENTER 1700

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an apparatus for pulling a single crystal and, more particularly, to an apparatus for pulling a single crystal used for pulling a single crystal of silicon or the like from a melt of a material for forming a crystal by a pulling method such as the Czochralski method (hereinafter, referred to as the CZ method).

2. Description of the Relevant Art

[0002] At present, the majority of silicon single crystals used for manufacturing a substrate for forming a circuit component of a LSI (large scale integrated circuit) and the like have been pulled by the CZ method. Fig. 3 is a diagrammatic sectional view of a conventional apparatus for pulling a single crystal used for the CZ method, and in the figure, reference numeral 21 represents a crucible.

[0003] The crucible 21 comprises a bottomed cylindrical quartz crucible 21a and a bottomed cylindrical graphite crucible 21b fitted on the outer side of the quartz crucible 21a. The crucible 21 is supported with a support shaft 28 which rotates in the direction shown by the arrow A in the figure at a prescribed speed. A heater 22 of a resistance heating type and a heat insulating mold 27 arranged around the heater 22 are concentrically arranged around the crucible 21. The crucible 21 is charged with a melt 23 of a material for forming a crystal which is melted by the heater 22. On the central axis of the crucible 21, a pulling shaft 24 made of a pulling rod or wire is suspended, and at the front thereof, a seed crystal 35 is held by a holder 24a. These members are arranged within a water cooled type apparatus body 29 wherein pressure can be controlled.

[0004] A window 29a is formed in the middle portion in the height direction of the

apparatus body 29. Above the window 29a in a slanting direction, a one-dimensional CCD camera 11 is arranged in such a position that a single crystal 36 during pulling can be seen through the window 29a, and the one-dimensional CCD camera 11 is connected to a diameter measuring means 8 of the single crystal 36. The diameter measuring means 8 is connected to a crucible ascent speed calculating means 9, which captures an input value of the pulled single crystal 36 from the diameter measuring means 8 and information on the pulled length from a pulling means 5 of the pulling shaft 24 to calculate a decrease in volume of the melt within the crucible 21, so as to calculate an ascent speed of the crucible 21 based on the decrease in the melt volume.

[0005] A method for pulling a single crystal 36 using the above apparatus for pulling a single crystal is described ^{with} ~~by~~ reference to Figs. 3 and 4. ^{(a)-(d)} Figs. 4(a)-4(d) are partial enlarged front views diagrammatically showing a seed crystal and the vicinity thereof in part of the steps in pulling a single crystal. ✓

[0006] Although it is not shown in Fig. 4, ^{(a)-(d)} the pressure within the apparatus body 29 is reduced, and an inert gas is introduced into the apparatus body 29 so as to make an inert gas atmosphere under reduced pressure therein. Then, the material for forming a crystal is melted by the heater 22 and is maintained for a period of time so as to sufficiently release gas contained in the melt 23. ✓

[0007] While the pulling shaft 24 is rotated on the same axis in the reverse direction of the support shaft 28 at a prescribed speed, the seed crystal 35 held by the holder 24a is caused to descend and is brought into contact with the melt 23. After the front portion of the seed crystal 35 is partially melted into the melt 23, the single crystal 36 begins to be pulled from the melt (the seeding step) (Fig. 4(a)). ✓

[0008] In making a crystal grow at the front of the seed crystal 35, the pulling shaft 24 is pulled at a higher speed than the below-described formation speed of a main body 36c, and the crystal is narrowed to have a prescribed diameter, leading to the formation of a

neck 36a (the necking step) (Fig. 4(b)).

[0009] By slowing down the pulling speed of the pulling shaft 24 (hereinafter, simply referred to as the pulling speed), the neck 36a is made to grow to have a prescribed diameter, leading to the formation of a shoulder 36b (the shoulder formation step) (Fig. 4(c)).

[0010] By pulling the pulling shaft 24 at a fixed rate, the main body 36c having a uniform diameter and a prescribed length is formed (the main body formation step) (Fig. 4(d)).

[0011] Furthermore, although it is not shown in Fig. 4, in order to prevent induction of high density dislocation to the single crystal 36 by a steep temperature gradient at the end, the diameter of the single crystal 36 is gradually decreased and the temperature of the whole single crystal 36 is gradually lowered, leading to the formation of an end-cone. Then, the single crystal 36 is separated from the melt 23. After the above steps, cooling the single crystal 36 leads to the completion of pulling the single crystal 36.

[0012] In pulling the single crystal 36, in order to obtain a good quality single crystal 36, it is necessary to drive the support shaft 28 using a motor 10 for crucible elevating to move ^{up} the crucible 21 ~~so as~~ to control the position of the crucible 21 so that the melt surface is always kept in a fixed position ^{with respect} to the heater 22. In the crucible ascent control, a method wherein the amount of ascent of the crucible 21 is calculated by calculating a decrease in volume of the melt 23 from the volume of the pulled single crystal 36 has been generally used.

[0013] Since the amount of ascent of the crucible 21 is calculated by calculating the decrease in volume of the melt 23 from the volume of the pulled single crystal 36 in the above crucible ascent control, the accurate volume of the pulled single crystal 36 need^s

to be obtained. In addition, in order to calculate the accurate amount of the crucible ascent from the decrease in volume of the melt 23, the accurate internal diameter of the crucible is required. However, in actual pulls, errors are introduced to the crucible ascent control by errors in measuring crystal weight and crystal diameters, changes in the internal diameter of the quartz crucible 21a due to softening thereof during pulling, and changes in the internal diameter of the quartz crucible 21a between batches originating in variations in manufacturing the quartz crucible 21a. Therefore, it is necessary to actually measure to control the level position during pulling the single crystal 36.

[0014] In order to solve the above problems, a method for measuring the level position has been disclosed in Japanese Kokai No. 63-281022. In the method for measuring the level position, the level position is calculated from the position of the mirror image of a radiation screen reflected in the melt surface. The method makes it possible to measure the level position during crystal pulling. ✓

[0015] Similarly to the method disclosed in the above publication, a method wherein the level position is controlled based on the mirror image position of a radiation screen reflected in the melt surface has been disclosed in Japanese Kokai No. 07-277879. In the method, by moving a crucible up and down so that the mirror image position of the radiation screen is kept fixed, the level position is controlled so as to be kept fixed. ✓

[0016] However, in ^{these} ~~these~~ methods, the inclination of the melt surface in which the mirror image of the radiation screen is reflected causes a change of the mirror image position even when the level position does not actually change, leading to the erroneous recognition and control of the level position. Factors of the inclination of the melt surface are changes in crystal diameter and changes in crucible rotational speed. Therefore, errors arise with changes in crystal diameter and changes in crucible rotational speed when the level position is controlled based on only the mirror image position of the radiation screen. ✓

[0017] Particularly, the shoulder formation step wherein the crystal diameter is increased to a desired diameter from the seed crystal is a problem. In the shoulder formation step, the inclination of the melt surface increases with ^{an} increase in crystal diameter. Therefore, when the level position control by which the mirror image position of the radiation screen is kept fixed is conducted in the shoulder formation step, the actual level positions before and after the shoulder formation step become different.

[0018] The same errors are also caused by changes in crystal diameter in the main body formation step. In addition, when the level position control is conducted based on only the mirror image position of the radiation screen on the melt surface, the occurrence of irregularity in measuring the level position makes it impossible to carry out the ascent/descent control of the crucible 21.

SUMMARY OF THE INVENTION

[0019] The present invention was accomplished in order to solve the above problems, and it is an object of the present invention to provide an apparatus for pulling a single crystal, wherein a flow of an inert gas to a single crystal to be grown, pressure in an apparatus body, and a temperature environment are always kept constant by keeping the melt level at a prescribed position in spite of changes in volume of a quartz crucible between batches and thermal deformation of the quartz crucible, so that high quality single crystals can be pulled.

[0020] In order to achieve the above object, an apparatus for pulling a single crystal (1) according to the present invention is ~~characterized by being~~ an apparatus for pulling a single crystal which has a lifting means of a crucible and a level position controlling means to control the level position in the crucible by calculating a crucible ascent speed based on a decrease in volume of a melt with pulling a single crystal so as to control the lifting means, ^{The apparatus} comprising a reference reflector arranged inside an apparatus body, a

level position measuring means to measure an actual level position by detecting a mirror image position of the reference reflector reflected in the melt surface using an optical device arranged outside the apparatus body, a crucible ascent speed adjustment value calculating means to calculate an adjustment value of the crucible ascent speed based on an output from the level position measuring means, an adjustment value adding means to add the adjustment value to the crucible ascent speed, and the level position controlling means to control the level position in the crucible by controlling the lifting means based on an output from the adjustment value adding means so as to control the crucible ascent speed.

^{B_{9a}}
[0021] Using the above apparatus for pulling a single crystal (1), having the reference reflector, the level position measuring means, the crucible ascent speed adjustment value calculating means and the adjustment value adding means, the crucible ascent speed is controlled by controlling the lifting means based on the output from the adjustment value adding means by the level position controlling means, while the level position in the crucible is controlled by calculating the crucible ascent speed based on the decrease in volume of the melt with single crystal pulling to control the lifting means by the level position controlling means. Therefore, even if the quartz crucible softens about the melting point of silicon and becomes deformed during pulling, the level position in the crucible can be controlled with high accuracy.

[0022] An apparatus for pulling a single crystal (2) according to the present invention ^{comprises} ~~is characterized by comprising~~ an adjustment value addition propriety judging means to judge the propriety of adding the adjustment value to the crucible ascent speed, based on a diameter of a pulling crystal, a level position measured by the level position measuring means, a distance between the crystal and the reference reflector, and a crucible rotational speed in the apparatus for pulling a single crystal (1).

^{this}
[0023] Using ~~the~~ above apparatus for pulling a single crystal (2), whether the adjustment value should be added to ~~the~~ crucible ascent speed or not is judged by the

adjustment value addition propriety judging means, based on the diameter of a pulling crystal, the level position measured by the level position measuring means, the distance between the crystal and the reference reflector, and the crucible rotational speed. These items are ^{the} chiefly ^{for} factors of determining the inclination of the melt surface in the process of single crystal pulling. The ^A situation where the selected values thereof for judgement are not satisfied under pulling conditions ^{indicates} means that the inclination of the melt surface is not suitable for measuring the level position, and that the measurement result is significantly affected by the inclination of the melt surface. In ^{this} that case, the adjustment value calculated from the level position measuring means is not added to the crucible ascent speed. Furthermore, even when there is such a problem in measuring the actual level position by detecting the mirror image position of the reference reflector reflected in the melt surface using the optical device arranged outside the apparatus body, the control wherein the level position in the crucible is controlled by calculating the crucible ascent speed based on the decrease in volume of the melt with single crystal pulling so as to control the lifting means is carried out. As a result, the influence of not adding the adjustment value to the crucible ascent speed on the level position change can be kept to a minimum.

[0024] An apparatus for pulling a single crystal (3) according to the present invention ^{comprises} is characterized by comprising an averaging means to average level positions measured by the level position measuring means in the apparatus for pulling a single crystal (1) or (2).

^{By} ^{using} ^{the} ^{above} ^{apparatus} ^{for} ^{pulling} ^a ^{single} ^{crystal} ⁽³⁾, it is possible to ^{negate} ^{reject} the effect of fluctuation of the melt surface. Another factor of errors in measuring the actual level position by detecting the mirror image position of the reference reflector reflected in the melt surface using the optical device arranged outside the apparatus body is the fluctuation of the melt surface. The fluctuation of the melt surface during measurement causes variations in measurement. The effect of the fluctuation of the melt surface can be ^{negated} ^{rejected} by the action of the averaging means to average the level

positions measured by the level position measuring means. It is desired that a period of time for averaging should be set in the range of 1 to 30 minutes or so.

[0026] An apparatus for pulling a single crystal (4) according to the present invention is ~~characterized by the~~ ^{has an} optical device constituting the level position measuring means being also used as an optical device for measuring a crystal diameter in any of the apparatus for pulling ^{the} a single crystal (1)-(3).

[0027] ^{By} ~~Using the above~~ apparatus for pulling a single crystal (4), the cost of manufacturing an apparatus for pulling a single crystal can be held down by using the optical device constituting the level position measuring means as the optical device for measuring a crystal diameter.

[0028] An apparatus for pulling a single crystal (5) according to the present invention ~~is~~ ^{comprises} ~~characterized by comprising~~ an automatic updating means to work out a conversion equation for converting a mirror image position of the reference reflector on the melt surface to an actual level position by automatically moving the crucible up and down from the initial position thereof. ^{This movement allows attainment of} ~~to obtain~~ the relationship between the mirror image position of the reference reflector on the melt surface and the level position and making the relationship approximate to a straight line in any of the apparatus for pulling ^{the} a single crystal (1)-(4).

[0029] Variations in the setting position of the optical device for detecting the mirror image position of the reference reflector and the setting position of the reference reflector are also factors of measurement errors in relation to the level position measurement. If the setting situations thereof do not change, it might be possible to accurately calculate the level position from the mirror image position of the reference reflector based on a conversion equation worked out from the geometric arrangement beforehand, but ^{this} ~~it~~ is actually difficult. Therefore, a conversion equation of the mirror image position of the reference reflector to the level position in the actual setting

situations is required. Using the above apparatus for pulling ^{the} a single crystal (5), having the automatic updating means to automate the activity of working out the conversion equation, it is possible to automatically find the conversion equation before crystal pulling ^{by} using the automatic updating means. ✓

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Fig. 1 is a diagrammatic sectional view showing an apparatus for pulling a single crystal according to an embodiment of the present invention;

[0031] Fig. 2 is a flow chart showing the operation of a level position controlling means in the apparatus for pulling a single crystal according to the embodiment;

[0032] Fig. 3 is a diagrammatic sectional view showing a conventional apparatus for pulling a single crystal; and

[0033] Figs. 4(a)-4(d) are partial enlarged front views diagrammatically showing a seed crystal and the vicinity thereof in part of the steps in pulling a single crystal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] The preferred embodiments of the apparatus for pulling a single crystal according to the present invention are described below by reference to ^{the} these Figures. ✓

Fig. 1 is a diagrammatic sectional view of an apparatus for pulling a single crystal according to an embodiment, and in the ^F figure, reference numeral 21 represents a crucible which is vertically movable. The crucible 21 comprises a bottomed cylindrical quartz crucible 21a and a bottomed cylindrical graphite crucible 21b fitted on the outer side of the quartz crucible 21a. The crucible 21 is supported with a support shaft 28 which rotates in the direction shown by the arrow A in the ^F figure at a prescribed speed. ✓
A heater 22 of a resistance heating type, and a heat insulating mold 27 arranged around

the heater 22 are concentrically arranged around the crucible 21. The crucible 21 is charged with a melt 23 of a material for forming a crystal which is melted by the heater 22. On the central axis of the crucible 21, a pulling shaft 24 made of a pulling rod or wire is suspended, and at the front thereof, a seed crystal 35 is held by a holder 24a. These members are arranged within a water cooled type apparatus body 29 wherein pressure can be controlled.

[0035] A window 29a is formed in the middle portion in the height direction of the apparatus body 29. Above the window 29a in a slanting direction, a one-dimensional CCD camera 11 is arranged in such a position that a single crystal 36 during pulling can be seen through the window 29a and the one-dimensional CCD camera 11 is connected to both a diameter measuring means 8 of the single crystal 36 and a level position measuring means 13. The one-dimensional CCD camera 11 has the function of measuring a diameter of the single crystal 36 as well as the function of measuring the level position of the melt 23. In the measurement of the level position, a two-dimensional CCD camera can be adopted in place of the one-dimensional CCD camera 11. Another CCD camera specifically for measuring the level position can be placed besides the one-dimensional CCD camera 11 for the diameter measuring means 8.

[0036] Above the crucible 21 within the apparatus body 29, a reference reflector 12 for detecting the level position is arranged, which also serves as a radiation screen to control the thermal history of the pulled single crystal 36. The reference reflector 12 is placed 22 mm or more apart from the straight body portion of the single crystal 36. It is also possible to use the reference reflector 12 separately from a radiation screen.

[0037] The one-dimensional CCD camera 11 is connected to the diameter measuring means 8, which is connected to a crucible ascent speed calculating means 9. The crucible ascent speed calculating means 9 captures an input value from the diameter measuring means 8 of the pulled single crystal 36 and information on the pulled length

from a pulling means 5 of the pulling shaft 24 to calculate a decrease in volume of the melt within the crucible 21, so as to calculate an ascent speed of the crucible 21 based on the decrease in volume of the melt.

[0038] Besides the diameter measuring means 8, the level position measuring means 13 is also connected to the one-dimensional CCD camera 11. The level position measuring means 13 receives an output from the one-dimensional CCD camera 11 to calculate the level position from the mirror image position of the reference reflector 12 reflected in the melt surface 23a of the melt 23. To the level position measuring means 13, both an averaging means 14 and an automatic updating means 18 are connected. The averaging means 14 receives an output from the level position measuring means 13 to average the measured values in a prescribed period of time, which is desirable to be set in the range of 1 to 30 minutes or so.

[0039] The automatic updating means 18 is used for automatically working out a conversion equation for converting the mirror image position of the reference reflector 12 on the melt surface 23a to the actual level position by automatically moving the crucible 21 up and down from the initial position thereof to obtain the relationship between the mirror image position of the reference reflector 12 on the melt surface 23a and the level position and making the relationship approximate to a straight line. Variations in the setting position of the one-dimensional CCD camera 11 for detecting the mirror image position of the reference reflector 12 and the setting position of the reference reflector 12 are also factors of measurement errors in the level position measurement. If the setting situations thereof do not change, it might be possible to calculate the level position from the mirror image position of the reference reflector 12 based on a conversion equation worked out from the geometric arrangement beforehand, but ^{this} it is actually difficult. Therefore, a conversion equation of the mirror image position of the reference reflector 12 to the level position in the actual setting situations is obtained by the automatic updating means 18.

[0040] In the present embodiment, the level position is actually changed by moving the crucible 21 up and down after the melting of a material for forming a crystal is completed and the initial level position becomes stable, and a conversion equation is obtained by making the relationship between the mirror image position of the reference reflector 12 and the level position approximate to a straight line using the automatic updating means 18. It is desired that the ascent/descent range of the crucible 21 at that time should be set to be ± 5 mm to the initial position. ✓

[0041] A crucible ascent speed adjustment value calculating means 15 is connected to the averaging means 14. By the crucible ascent speed adjustment value calculating means 15, an adjustment value for adjusting the control error of the melt position which arises in the case of the control ^{being} based on a crucible ascent speed calculated in the crucible ascent speed calculating means 9 is calculated. How to calculate the adjustment value is that after the measured value of the level position, at the first point when it is judged to be able to be added by a below-described adjustment value addition propriety judging means 16, is set to be the initial position, an adjustment value of the crucible ascent speed is calculated by calculating the level position shifted from the initial position. ✓
✓
✓
✓
✓

[0042] The adjustment value addition propriety judging means 16 to judge ^{the} irregularity in measuring the level position is connected to the crucible ascent speed adjustment value calculating means 15. The criteria for judgement in the adjustment value addition propriety judging means 16 are: the upper and lower limits of a crystal diameter are within the range of ± 2 mm to a desired diameter of a main body 36c of the single crystal 36; the upper and lower limits of the level position are within the range of ± 5 mm to the initial value of the level position; the lower limit of the distance between the single crystal 36 and the reference reflector 12 is 22 mm; and the upper and lower limits of the rotational speed of the crucible 21 are within the range of ± 10 rpm to the rotational speed of the crucible 21 at the starting point of pulling the main body 36c of the single crystal 36. When these conditions are not satisfied, the adjustment value ✓
✓

calculated in the crucible ascent speed adjustment value calculating means 15 is not allowed to be added to the ascent speed of the crucible 21 calculated in the crucible ascent speed calculating means 9 by an adjustment value adding means 17. ←

[0043] In the settings of the present embodiment, the above upper and lower limits of d_{λ}^{the} crystal diameter do not satisfy the condition of within the range of ± 2 mm to a desired diameter of the main body 36c of the single crystal 36 during $\overset{a}{\underset{\lambda}{pulling}}$ a shoulder 36b of the single crystal 36. Therefore, the level position control is performed based on the crucible ascent speed calculated in the crucible ascent speed calculating means 9. However, the shoulder 36b of the single crystal 36 is very small in volume, so that the control error of the level position thereby can be kept in a very small range. ✓

[0044] According to the above construction, in the apparatus for pulling a single crystal according to the embodiment, two systems of controlling the level position during pulling $\overset{the}{\underset{\lambda}{a}}$ single crystal 36, a crucible ascent speed based on a decrease in volume of the melt 23 with pulling the single crystal 36 and an output from the crucible ascent speed adjustment value calculating means 15 based on the measurement result of the level position measured from the mirror image position of the reference reflector 12 on the melt surface 23a, are included. ✓

[0045] In the apparatus for pulling a single crystal according to the embodiment, as one system, the level position is controlled by calculating the ascent speed of the crucible 21 from both the measured value of the crystal diameter of the single crystal 36 and the pulling speed thereof. The crucible ascent speed is calculated based on the below equation (1).

$$V_f = (D_{si}^2 P_s / D_{cur}^2 P_L) \times (V_{si} - V_{cur}) + V_{cur} \quad \cdot \cdot \cdot \quad (1)$$

where V_f : crucible ascent speed

P_s : specific gravity of solid silicon

P_L : specific gravity of liquid silicon

D_{si} : crystal diameter
 D_{cur} : quartz crucible internal diameter
 V_{si} : crystal pulling speed
 V_{cur} : preceding crucible ascent speed

[0046] Thus, an accurate value of the internal diameter of the quartz crucible 21a is required for calculating the crucible ascent speed. However, in some cases, the quartz crucible 21a softens ^{at} about the melting point of silicon and becomes deformed during pulling. Therefore, in the apparatus for pulling a single crystal according to the embodiment, the level position is measured from the mirror image position on the melt surface 23a of the reference reflector 12 arranged inside the apparatus body 29, and the control error in the level position control based on the crucible ascent speed calculated from the decrease of the melt 23 is calculated. Then, an adjustment value of the ascent speed of the crucible 21 is calculated from the calculated control error and is added to the crucible ascent speed, so that the level position is controlled thereby with higher accuracy. The crucible ascent speed adjustment value is calculated based on the below equation (2).

$$\begin{aligned}
 V \text{ (mm/min)} &= V_f \text{ (mm/min)} + V_{adj} \text{ (mm/min)} \quad \cdot \cdot \cdot \quad (2) \\
 V_{adj} &= \sum \Delta V_{adj} (i) \\
 \Delta V_{adj} (i) &= P \times \{H_i \text{ (mm)} - H_{i-1} \text{ (mm)}\} + I \times \{H_i \text{ (mm)} - H_0 \text{ (mm)}\} \\
 &\quad + D \times \{H_i \text{ (mm)} - 2H_{i-1} \text{ (mm)} + H_{i-2} \text{ (mm)}\}
 \end{aligned}$$

where V: crucible ascent speed after adjusting level position change

V_{adj} : crucible ascent speed adjustment value

V_f : crucible ascent speed

H_0 : reference level position

H_i : ith measured value of level position

P, I, D: control constants

P_s : specific gravity of solid silicon

P_L : specific gravity of liquid silicon

[0047] However, in some cases, errors are introduced to the level position measurement from the mirror image position of the reference reflector 12 on the melt surface 23a. The prime cause of the measurement errors is ^{the} inclination of the melt surface 23a. When the inclination of the melt surface 23a changes during measurement, the mirror image position of the reference reflector 12 reflected in the melt surface 23a changes, resulting in an error in measuring the level position. The inclination of the melt surface 23a is varied by two factors. ✓

[0048] The first factor is the surface tension caused by ~~the~~ ^{the} pulling single crystal 36. During crystal pulling, the melt surface 23a is lifted by the surface tension and becomes inclined. The melt surface 23a closer to the single crystal 36 is more inclined, while the melt surface 23a ^{further} ~~farther~~ from the single crystal 36 is less inclined. Therefore, the larger the crystal diameter becomes, the ^{greater} ~~more greatly~~ the mirror image position of the reference reflector 12 during crystal pulling is influenced by the inclination of the melt surface 23a. Here, the inclination of the melt surface 23a on the same melt surface 23a does not change when the distance between the single crystal 36 and the reference reflector 12 is fixed. Therefore, the measurement error of the level position caused by the change of the inclination of the melt surface 23a during crystal pulling is influenced by the change of the crystal diameter and the change of the crystal position during pulling. ✓

[0049] The second factor of changing the inclination of the melt surface 23a is the influence of centrifugal force which arises with the rotation of the crucible 21. Since the melt 23 within the crucible 21 rotates with the rotation of the crucible 21, the melt 23 is pushed to the outer regions by the centrifugal force, leading to the inclination of the melt surface 23a. Since the inclination is chiefly determined by the rotational speed of the melt 23, the inclination of the melt 23a changes with the change of the rotational speed of the crucible 21 during pulling, so that the mirror image position of the reference reflector 12 also changes. ✓

[0050] Therefore, in the adjustment value addition propriety judging means 16 of the ascent speed of the crucible 21 of the apparatus according to the embodiment, whether adding the adjustment value is right or not is judged based on the selected upper and lower limits of the crystal diameter, the upper and lower limits of the level position, the selected lower limit of the distance between the single crystal 36 and the reference reflector 12, and the selected upper and lower limits of the rotational speed of the crucible 21, which are factors of changing the inclination of the melt 23a, so that the measurement error caused by the change of the inclination of the melt 23a^{is} becomes allowable below allowance.

[0051] Another factor of errors in relation to the measurement of the level position is fluctuation of the melt surface 23a. When the melt surface 23a fluctuates during measurement, variations in measurement are caused. The influence of the fluctuation of the melt surface 23a can be ^{negated} rejected by the operation of the averaging means 14 to average the measured values of the level positions. It is appropriate that the period of time for averaging should be set in the range of 1 to 30 minutes or so.

[0052] Variations in the setting position of the one-dimensional CCD camera 11 for detecting the mirror image position of the reference reflector 12 and the setting position of the reference reflector 12 are also factors of measurement errors in relation to the level position measurement. If the setting situations thereof do not change, it might be possible to uniformly calculate the level position from the mirror image position of the reference reflector 12 based on a conversion equation worked out from the geometric arrangement beforehand, but ^{this} it is actually difficult. Therefore, a conversion equation of the mirror image position of the reference reflector 12 to the level position in the actual setting situations of the one-dimensional CCD camera 11 and the reference reflector 12 is required. The conversion equation can be obtained by moving the crucible 21 up and down to change the level position. ^{By} Using the apparatus for pulling a single crystal according to the embodiment, having the automatic updating means 18 to automate the activity of working out the conversion equation, it is possible to automatically find the

conversion equation before pulling the single crystal 36 using the automatic updating means 18.

[0053] Since the reference reflector 12 is a structure above and in the proximity of the melt surface 23a, it needs to be made of a material which does not contaminate the melt 23 and can endure high temperatures. As a component of the reference reflector 12, carbon can be exemplified. In addition, if the distance between the single crystal 36 and a radiation screen can be ensured to be above the selected lower limit of the distance between the single crystal 36 and the reference reflector 12, the radiation screen for controlling the thermal history of the single crystal 36 can be also used as the reference reflector 12.

[0054] As an optical device for measuring the mirror image position of the reference reflector 12, a normal two-dimensional CCD camera, one-dimensional CCD camera, or the like can be used. When the crystal diameter is measured during crystal pulling using the one-dimensional CCD camera 11 and the reference reflector 12 is placed within the field of view of the measurement, the one-dimensional CCD camera 11 for measuring a crystal diameter can be also used as that for measuring the level position, if the distance between the single crystal 36 and the reference reflector 12 is ensured to be above the selected lower limit thereof.

[0055] The operation of the level position controlling means 20 of the apparatus for pulling a single crystal according to the embodiment is described below by reference to the flow chart shown in Fig. 2.

[0056] In Step 1, ^(S1) whether the melting of the material for forming a crystal is completed or not is judged. When the melting of the material for forming a crystal is judged to be ^{not} completed in S1, the ^{operation} means waits for the completion of the melting thereof. On the other hand, when the melting of the material for forming a crystal is judged to be completed, the operation proceeds to Step 2, ^(S2) wherein the crucible 21 is caused to move

up and down within the range of ± 5 mm to the initial position. Then, ^{the process} it goes to Step 3_λ ^(S3) wherein a conversion equation of the mirror image position to the level position is obtained from the change of the mirror image position of the reference reflector 12 with the ascent/descent of the crucible 21.

[0057] After the conversion equation is obtained, pulling ^{of the} a single crystal 36 is started ^{in Step 4} ^(S4) (Step 4). With the start of pulling, measured values of the pulling speed of the pulling shaft 24 and the crystal diameter are captured ^{in Step 5 (S5)} (Step 5), and the ascent speed of the crucible 21 is calculated based on these values using the equation (1) ^{in Step 6 (S6)} (Step 6). Then, the level position is calculated from the mirror image position on the melt surface 23a of the reference reflector 12 placed inside the apparatus body 29 ^{in Step 7 (S7)} (Step 7), averaging is conducted on the calculated values of the level positions ^{in Step 8 (S8)} (Step 8), and an adjustment value of the ascent speed of the crucible 21 is calculated from the averaged measured value based on the equation (2) ^{in Step 9 (S9)} (Step 9).

[0058] The operation proceeds to Step 10_λ ^(S10) wherein the propriety of adding the adjustment value calculated in Step 9_λ ^(S9) to the ascent speed of the crucible 21 is judged. The judgement is carried out based on whether or not the upper and lower limits of the crystal diameter are within the range of ± 2 mm to a desired diameter of the main body 36c, the upper and lower limits of the level position are within the range of ± 5 mm to the initial level position, the lower limit of the distance between the single crystal 36 and the reference reflector 12 is 22 mm, and the upper and lower limits of the crucible rotational speed are within the range of ± 10 rpm to the crucible rotational speed at the early stage of forming the main body 36c. When adding the adjustment value to the ascent speed of the crucible 21 is judged to be ^{acceptable} right ^(S10) in Step 10_λ, the operation goes to Step 11_λ ^(S11) wherein adding the adjustment value is conducted, and then, the ascent speed of the crucible 21 is controlled based on the adjusted value ^{in Step 12 (S12)} (Step 12). On the other hand, when adding the adjustment value to the ascent speed of the crucible 21 is judged to be wrong in Step 10_λ ^(S10), it ^{(S11) is bypassed and the operation} bypasses Step 11_λ and goes to Step 12_λ ^(S12) wherein the ascent speed of the crucible 21 is controlled based on the value calculated in Step 6_λ ^(S6).

By a
[0059] Using the apparatus for pulling a single crystal according to the embodiment, it is possible to control the level position in the crucible 21 by the level position controlling means 20, which calculates the crucible ascent speed based on a decrease in the melt volume with ^{the} pulling ^{of the} a single crystal 36 so as to control a motor 10 for crucible lifting. Furthermore, ^{by} using the apparatus for pulling a single crystal according to the embodiment, having the reference reflector 12, level position measuring means 13, crucible ascent speed adjustment value calculating means 15, and adjustment value adding means 17, the level position controlling means 20 controls the crucible ascent speed by controlling the motor 10 for crucible lifting based on an output from the adjustment value adding means 17. As a result, even if the quartz crucible 21a softens ^{at} about the melting point of silicon and becomes deformed during pulling, the level position in the quartz crucible 21a can be controlled with higher accuracy.

By a
[0060] Using the apparatus for pulling a single crystal according to the embodiment, the adjustment value addition propriety judging means 16 judges whether adding the adjustment value to the crucible ascent speed is appropriate or not based on the crystal diameter of the pulling single crystal 36, the level position measured by the level position measuring means 13, the distance between the single crystal 36 and the reference reflector 12, and the crucible rotational speed. These items are ^{the} chiefly factors of determining the inclination of the melt surface 23a in the apparatus for pulling a single crystal. Therefore, the situation where the selected values thereof for judgement are not met under pulling conditions ^{indicates} means that the inclination of the melt surface 23a is not adequate ^{with respect} to the level position measurement, and that the measurement result is significantly influenced by the inclination of the melt surface 23a. In ^{this} that case, the adjustment value calculated from the level position measuring means 13 is not added to the crucible ascent speed. In addition, even if there is such a problem in measuring the actual level position by detecting the mirror image position of the reference reflector 12 reflected in the melt surface 23a using the one-dimensional CCD camera 11 arranged outside the apparatus body 29, the control, wherein the level position in the crucible 21

is controlled by calculating the crucible ascent speed based on a decrease in the melt volume with ^{the} pulling ^{of the} a single crystal 36 so as to control the motor 10 for crucible lifting, is conducted, so that the influence on the level position change can be kept to a minimum. ✓

^{By} [0061] Using the apparatus for pulling a single crystal according to the embodiment, it is possible to ^{negate} reject the influence of fluctuation of the melt surface 23a. Since the mirror image position of the reference reflector 12 reflected in the melt surface 23a is detected using the one-dimensional CCD camera 11 arranged outside the apparatus body 29, another factor of errors in the level position measurement wherein the actual level position is measured is the fluctuation of the melt surface 23a. The fluctuation of the melt surface 23a during measurement causes variations in measured values. The effect of the fluctuation of the melt surface 23a is ^{negated} rejected by the action of the averaging means 14 to average the level positions measured by the level position measuring means 13. ✓

^{By} [0062] Using the apparatus for pulling a single crystal according to the embodiment, wherein the one-dimensional CCD camera 11 constituting the level position measuring means 13 is also used ~~as a one-dimensional CCD camera 11~~ for measuring a crystal diameter, the cost of manufacturing the apparatus for pulling a single crystal can be held down. In addition, ^{by} using the apparatus for pulling a single crystal according to the embodiment, having the automatic updating means 18 to automate the activity of working out a conversion equation of the mirror image position of the reference reflector 12 in the actually placed ^{position} situation to the level position, it is possible to automatically find the conversion equation before crystal pulling using the automatic updating means 18. ✓

EXAMPLES AND COMPARATIVE EXAMPLES

[0063] An example of the level position control actually conducted using an ^{exemplary} apparatus ✓

for pulling a single crystal according to ~~an example~~ of the present invention is described below. The exemplary ^{based on the}

^{Apparatus for pulling a single crystal} ~~according to Example~~: apparatus shown in Fig. 1, has the following characteristics:

Internal diameter of ^{the} crucible 21: 22 inches;

Weight of material for forming a single crystal: 100 kg;

Mean diameter of ^{the} single crystal 36: 8 inches;

Distance between ^{the} reference reflector 12 and ^{the} main body 36c of ^{the} single crystal 36: 22 mm or more;

Period of time for averaging in ^{the} averaging means 14: 10 minutes; and

Criteria for judgement in ^{the} adjustment value addition propriety judging means 16

: the upper and lower limits of the crystal diameter are within the range of ± 2 mm to a desired diameter of the main body 36c,

: the upper and lower limits of the level position are within the range of ± 5 mm to the initial level position,

: the lower limit of the distance between the single crystal 36 and the reference reflector 12 is 22 mm, and

: the upper and lower limits of the crucible rotational speed are within the range of ± 10 rpm to the crucible rotational speed at an early stage of forming the main body 36c.

[0064] The conversion equation was obtained by the automatic updating means 18 whereby the level position was actually changed by moving the crucible 21 up and down after the melting of the material was finished and the initial level position was set, and the relationship between the mirror image position of the reference reflector 12 and the level position was made approximate to a straight line. The ascent/descent range of the crucible 21 at that time was set within the range of ± 5 mm to the initial position.

[0065] In the settings of the Example, since the condition of the upper and lower limits of the crystal diameter was not satisfied during pulling the shoulder 36b, the level

position control was conducted based on the output from the crucible ascent speed calculating means 9. However, the shoulder 36b was very small in volume, so that the error in controlling the level position was very small.

[0066] In the Example, it could be confirmed that it was possible to control the level position during pulling the single crystal 36 within the range of ± 1 mm to the initial level position.

ABSTRACT OF THE DISCLOSURE

~~The present invention was achieved in order to provide~~ ^{is used to pull} an apparatus ^a for pulling a single crystal, wherein a flow of an inert gas to ^{the} a single crystal to be grown, pressure in an apparatus body, and a temperature environment are always kept constant by keeping ^a the melt level at a prescribed position in spite of changes in volume of a quartz crucible between batches and thermal deformation of the quartz crucible, so that high quality single crystals can be pulled. ^{The apparatus has} ~~comprising~~ a reference reflector arranged inside an apparatus body, a level position measuring ^{unit} means to measure an actual level position by detecting a mirror image position of the reference reflector reflected in the melt surface using a one-dimensional CCD camera arranged outside the apparatus body, a crucible ascent speed adjustment value calculating ^{unit} means to calculate an adjustment value of the crucible ascent speed based on an output from the level position measuring ^{unit} means, an adjustment value adding ^{unit} means to add the adjustment value to the crucible ascent speed, and a level position controlling ^{unit} means to control the level position in the crucible by controlling a motor for crucible lifting based on an output from the adjustment value adding means to control the crucible ascent speed.